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LABORATORY CONTROL OF WATER SUPPLIES

H. W. Streeter

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By

H. W. STREETER

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LABORATORY CONTROL OF WATER SUPPLIES [1]

By H. W. STREETER, *Sanitary Engineer Director,*
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Although the importance of the laboratory in the sanitary control of water supplies has been well established for many years, it has increased greatly during the past two decades. During this time, laboratory methods have undergone numerous improvements and refinements, and their range of application has embraced an ever-broadening field. Within recent years, laboratory control methods have been extended to include not only the sanitation of water supplies but also the conditioning of water for specific uses, both domestic and industrial, not directly associated with hygienic safety. Although the present paper deals primarily with laboratory control methods for the sanitation of water supplies, it also touches upon some of the newer developments in nonsanitary water conditioning, such as, for example, water softening and corrosion control.

In the United States, laboratory control of water supplies has been practiced for over 50 years. The elaboration and improvement of control methods have been associated in this country mainly with the following developments:

1. The publication, since 1905, of eight editions of Standard Methods for the Examination of Water and Sewage, originally issued by a committee of the American Public Health Association, and now issued jointly with the American Water Works Association and the Federation of Sewage Works Associations.

2. The advances in water treatment and its control which have been made in various countries, thus stimulating research on improved laboratory methods.

3. The general advances made in the sciences of physics, chemistry, and bacteriology, which have furnished new tools, devices, and techniques, as well as new concepts in their application to water quality control.

4. The development of drinking water standards by the United States Public Health Service, and their general adoption by our various states as a basis of their requirements for the quality of public water supplies.

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[1] From the Sanitary Engineering Division. Presented at Inter-American Conference on Sanitary Engineering, Rio de Janeiro, June 11, 1946.

5. The increasing pollution of surface sources of water supply by sewage and industrial wastes, together with a progressive depletion and deterioration of ground water supplies in certain parts of the country, these circumstances having tended to focus attention on the need for improved methods of laboratory control in dealing with problems of water supply sanitation.

The general types of problems to which laboratory control of water quality is applicable may be listed as follows:

1. Watershed protection for surface sources of water supply.

2. Treatment of public water supplies, both for sanitary protection and for conditioning with reference to the removal of various undesirable constituents or characteristics.

3. Protection and treatment of water supplies derived from underground sources.

4. Protection of water in distribution systems, including pipe systems and distribution reservoirs.

5. Conditioning treatment of water for industrial and other uses having special quality requirements.

Although certain control tests and their applications are common to nearly all of these five categories, the nature of each one of them, and also the technical questions involved, are so distinctive as to justify separate consideration. In the portion of this paper which follows, the control problems in each category, together with general methods applicable to certain problems, will be discussed, largely, however, from the viewpoint of the sanitary engineer, who is less concerned with details of laboratory procedures than with the interpretation and application of results, and with the proper selection of tests appropriate to each type of problem.

WATERSHED PROTECTION

The sanitary protection of sources of water supply located in surface watershed areas has been studied and practiced for many years by several of the larger cities of my country, including New York City, Boston, and San Francisco. At New York, the existence of a considerable and growing population on the watersheds from which the municipal water supply is derived has constituted a difficult and increasingly complex problem in sanitation, particularly in view of the fact that treatment of the water supply has been limited thus far to simple chlorination. For this reason, the methods of sanitation, together with their laboratory control, followed at New York afford a good example of such methods in an advanced state of development.

The greater part of the surface water supply for this city is derived from three major watersheds, with extensive development of impounding reservoirs. Systematic and frequent laboratory examination of the water flowing into and out of the reservoirs, and of the water in tributary streams, has been carried out over a period of many years, including bacteriological, chemical, and biological determinations. The record of these examinations has established a series of normal conditions with respect to the quality of water at each sampling point, whereby any abnormality can be readily detected. Any departure from such a normal condition is a matter for immediate investigation, as indicating some unusual condition affecting the quality of water at a given sampling point. The chemical examination of water at the various sampling points has included free ammonia, nitrite, nitrate, total and volatile solids, chloride, and permanganate oxygen consumed, as well as turbidity, color, alkalinity, and total hardness. In addition, routine examination of the effluents of several sewage treatment plants, operated for watershed protection, is carried out regularly. Bacteriological examinations of the stream and reservoir waters have included 24-hour plate counts at 37° C. and quantitative tests for coliform bacteria. Small streams containing drainage water from farms or small villages receive special examination for coliform bacteria.

A highly important measure of laboratory control in the operation of the water impoundment areas is a systematic biological examination of water in each reservoir, with particular reference to microscopic organisms which may cause undesirable tastes and odors in the effluent from the reservoir. In the New York reservoirs, the identification and enumeration of these organisms, is carried out very systematically, in order to forestall the appearance of "blooms" of undesirable organisms by means of protective treatment with copper sulphate. Whenever such treatment is found necessary, the reservoir water is sampled and examined for whatever period of time may be necessary after treatment, in order to ensure that it has been effective. In this manner, invasion of the reservoirs by heavy growths of undesirable organisms is forestalled and prevented.

Wherever, in general, filtration treatment of impounded waters is practiced, as is the case in a large number of other cities of the United States, continual vigilance must be exercised against growths of diatoms and other filter-clogging organisms, in addition to those causing tastes and odors. These organisms, when prevalent, are often responsible for reducing the output capacity of a filtration plant, because of shortened filter "runs" and conse-

quently increased amounts of filtered water required to wash the filters. Constant vigilance is required, during certain seasons of the year, in order to prevent such conditions from becoming established.

Before concluding this section of the discussion, a few words are desirable concerning the collection and transportation of water samples intended for bacteriological examination. Before a sample is taken from a faucet, the water should be allowed to flow for at least 5 minutes if the tap is in regular use, or for a longer period if it is used only occasionally. When taken from a pump, similar precautions are necessary. Sample bottles should of course be scrupulously clean and sterilized by heat at 170° C. for at least 1 hour, or by steam at 15 lbs. pressure for 15 minutes. The bottle neck and stopper should be protected from dust or other contamination by wrapping with tin or aluminum foil, or a paper substitute, before sterilization. When samples are collected from a lake or a stream, a sampling rod, or a weighted frame supported by a suitable cord or chain, may be used. Various devices of this kind are in general use. In collecting a sample from a flowing stream, caution must be exercised in dipping the bottle upstream from the boat or person collecting the sample. Because of rapid changes which may take place in the bacterial content of a sample when stored at high temperatures, it should be iced immediately after collection and during transportation to the laboratory if examination is to be delayed for more than a short period of time. Iced samples, kept at temperatures between 6° and 10° C. usually will undergo little change until after about 12 hours.

WATER TREATMENT CONTROL

The primary objectives of laboratory control in water purification are (1) to maintain the efficiency and economy of treatment, and (2) to produce a final effluent of uniformly acceptable quality, regardless of variations in the character of raw water as delivered for treatment. Seasonal changes, especially in water temperature, sometimes are a complicating element in water treatment control, because they affect the efficiency of coagulation and, at certain seasons, of sedimentation as well. The appearance of substances causing undesirable tastes and odors in the water under treatment is a further complication, often connected with certain seasons.

The routine control tests ordinarily used in water purification include the bacteriological plate count, at 20° C. or 37° C.; the coliform bacterial count; physical tests such as temperature, tur-

bidity and color; chemical tests such as alkalinity, pH, total and non-carbonate hardness, residual chlorine, and special determinations for CO_2, iron, aluminum, etc., as occasion may require. The chemical analysis of fuels, coagulants, hypochlorites, etc., is also generally the task of the plant laboratory.

The bacteriological count at 37° C., on a standard nutrient agar medium, after 24 hours incubation, is generally preferred to the 20° count. For the coliform bacteria test, standard lactose broth is the usual presumptive medium, with brilliant green lactose bile broth as the confirmatory medium, though some laboratory workers prefer the Endo or Eosin Methylene Blue plating medium for confirmatory work, together with the transplanting of typical colonies back to lactose broth for final test as to gas formation. A microscopical examination of a Gram stain smear to indicate that the organisms are Gram-negative, nonspore-forming and nonmotile, completes the test for this group.

During the past 20 years, the use of the "most probable number" method of enumeration for coliform bacteria from fermentation tube tests has gained widespread favor, though in some of our smaller water laboratories the simplicity of the "Phelps index", particularly when determined from single-tube dilutions of the sample, has caused its use to be continued in preference to the most probable number method. The theory underlying the "M.P.N." enumeration, which was originally described by MacCrady, is based on the assumption of random distribution of coliform organisms in a sample, and on the relative probability that any portion of water drawn from a sample may contain the true average number present. The number corresponding to the maximum probability in a series of drawings is the most probable number. Recent editions of "Standard Methods" have given "most probable numbers" per milliliter of sample corresponding to various series of positive and negative results obtained in multiple-dilution plantings of a sample in single, duplicate, triplicate, etc., sample portions.

The Phelps index is the reciprocal of the smallest fractional portion of a sample giving a positive test for coliform bacteria in a series of plantings. This method is based on the assumption that the distribution of coliform bacteria in a sample is uniform, rather than random, and that the smallest portion giving a positive test contains a single organism of this group. Let us assume a series of single-tube plantings, of 0.001 ml., 0.01 ml., 0.1 ml., and 1.0 ml., from a sample, and results giving a negative test in 0.001 ml., and positive tests in the 0.01 ml., 0.1 ml., and 1.0 ml. In this case the Phelps index would be $1 \div 0.01$, or 100 per ml.

Several experiments on samples of water containing known concentrations of coliform organisms have shown that the M.P.N. concept of enumeration is the more accurate, and gives results which, within their limits of error, more closely approximate the actual numbers of coliform bacteria present in a sample.

The shortcomings of a method of bacterial counting based on the fermentation tube test with sample portions of various sizes have been recognized. As a consequence, efforts have been made to develop a direct plating method of enumerating coliform bacteria. Some of the selective culture media thus developed have yielded fairly good results in highly skilled hands. The direct-plating method has a basic weakness, however, for routine work on drinking water supplies, in that it is not sufficiently delicate to detect coliform densities at the drinking water standard level, unless large volumes of water (i.e. 100 ml. or more) are planted in the plating medium. For stream and lake waters containing larger numbers of coliform organisms, the possibilities of using this method are more promising.

Mention has been made of the United States Public Health Service's bacteriological standards for drinking waters These standards require, in effect that in any monthly series of sample examinations, not more than 10 percent of the 10 ml. portions tested shall show the presence of organisms of the coliform group. Occasionally, individual samples may show a positive result in three or more of the five 10 ml. sample portions constituting a standard sample, provided that this shall not be allowable if it occurs in consecutive samples or in more than 5 percent of the standard samples when 20 or more samples are examined per month, or in more than one sample when less than 20 samples have been examined per month. The quantitative meaning of this requirement is that a given drinking water shall not be shown to contain an average most probable number of more than 1 per 100 ml. in any month, as a rounded figure, or of more than 9 per 100 ml. in more than 5 percent of the samples examined per month. The same standards permit the alternative use of 100 ml. sample portions for testing purposes, the allowable percentages of positive results being fixed in this case so as to permit the same limits of density as when 10 ml. standard portions are planted. Comparison of this standard with the classification suggested by the Committee of Ministry of Health (1930) for water in Britain indicates that the limiting coliform bacteria requirement for "highly satisfactory" and "satisfactory" waters conforms very closely to the requirements of the standard above described.

The physical and chemical control tests commonly used in water purification depend to some extent on the type and purpose of treatment. For sanitary purification, as previously noted, the physical tests usually include temperature, turbidity, color, and threshold odor, if present. Chemical tests include alkalinity, hydrogen ion concentration (pH), and residual chlorine, together with total and non-carbonate hardness if a record of this constituent is important in connection with domestic or industrial use of a water supply. Biological examinations of the untreated water are necessary whenever unusual tastes and odors are present in the water, or whenever undue clogging of filters is prevalent. Algae and diatoms are particular offenders in these two respects. A routine check examination of the raw water for taste producing and filter-clogging organisms at frequent intervals during the season of their prevalence is advisable, as previously noted under "Watershed Protection", in order to detect any early signs of an increase in one or more of these species. Routine daily examinations of the raw, settled, and filtered water for turbidity or color, of the raw and filtered waters for alkalinity and pH value, and of the final effluent for residual chlorine, are the usual minimum requirements for effective plant operation control.

Whenever water softening, or anti-corrosion treatment, is carried out in connection with purification, an accurate and frequent routine control of the mineral content and stability of the water at various stages of treatment is necessary. In this connection, the control tests will vary with the type of treatment. For example, with lime-soda treatment for softening, a frequent (sometimes hourly) check on the total, carbonate, and non-carbonate hardness of the raw and treated water, together with tests of the residual mono-carbonate, bicarbonate, and caustic alkalinity of the treated water, are highly important guides to proper treatment. The pH of the treated water also is an important routine test.

In general, an effort is made in water softening for domestic use, to reduce the total hardness to 50 p.p.m. or less. Partial lime softening will remove free carbon dioxide, will reduce calcium bicarbonate hardness, and will eliminate almost completely magnesium in any form because of the high degree of insolubility of $Mg(OH)_2$. The excess-lime method, which consists of liming the water to about 50 p.p.m. of caustic alkalinity, will remove CO_2 and most of the carbonate, and will leave a high pH value (about 10.5 or more). Ordinarily, the pH of the treated water is reduced by recarbonation with CO_2 to pH 9.4, or by blending with raw water. This method of treatment yields an effluent of good bacterial qual-

ity at ordinary temperatures because of the marked bactericidal effect of excess causticity. The lime-soda method removes the bulk of carbonate and noncarbonate hardness. In controlling this method, jar tests are always desirable, particularly when high soda ash dosage is required. The lime-soda method may be controlled by proper selection of pH so as to remove the calcium from a water without much reduction in magnesium. This is important in some industrial uses of water, where magnesium is desirable, and also for economy of treatment.

The use of base-exchange zeolites for water softening is increasing in municipal treatment plants, in addition to its household applications. In this process, zeolites are used belonging to the group of materials known as alumino-silicates, which have the property of exchanging their sodium ion for calcium and magnesium ions in water brought into contact with them. Eventually, when the sodium of the zeolite has been replaced by calcium and magnesium, the softening reaction is stopped, and the zeolite must be regenerated by applying a strong brine solution of NaCl. Regeneration simply reverses the softening reaction and restores the original base-exchange property of the zeolite. This practice may be continued with little loss or shrinkage of the material (about 3 percent per year).

The principal control test for a zeolite process is the soap hardness titration on the effluent, using standard soap solution or a more concentrated solution if desired. After regeneration, completeness of flushing out the brine may be checked by means of the standard chloride test, using a standard silver nitrate solution, with potassium chromate as an indicator. For checking the performance of a softener, testing composited samples for pH, alkalinity, and total and noncarbonate hardness is helpful. An occasional carbonate stability test is advisable, using the "marble test" procedure, as described below.

Corrosion control, as now practiced, consists in the proper regulation of those constituents of water which cause metal corrosion, or in the introduction of substances forming inhibitive deposits on pipe and other surfaces exposed to water. Among the active pipe corroders are dissolved oxygen and carbon dioxide, and also acids and acid salts, notably chlorides and sulphates. Many corrosive waters may be conditioned by raising their pH. Lime treatment of low-calcium waters, and soda-ash treatment of hard waters low in alkalinity and CO_2, are effective. A direct and simple test for under or over saturation of a water with calcium carbonate is the "marble test", which consists, briefly, in shaking a sample with

marble dust in a bottle for a period ranging from 10 minutes upwards, then settling the mixture, pipetting off a sample of the clear liquid, and noting the change in its pH and alkalinity as compared with the original sample. If this change is an increase, it denotes that the original sample was undersaturated with calcium carbonate and therefore likely to be corrosive. If it diminishes, it indicates over saturation and the likelihood of noncorrosion. A balanced water by this test would neither dissolve nor release calcium carbonate. The test may be utilized to estimate the amount of alkali needed to bring a water into calcium equilibrium.

WATER CHLORINATION

The laboratory control of water chlorination involves bacteriological tests to check the quality of the treated effluent, and chemical tests to determine whether a proper residual concentration of chlorine or chloramine is being carried in the treated water in order to safeguard its quality. In waters having an appreciable chlorine demand, frequent tests designed to measure this demand are also customary. Recent developments in the elaboration of simple chlorination have resulted in new tests, or adaptations of older tests, designed to distinguish between free active chlorine and chloramines. The reason has been the rediscovery of the markedly greater bactericidal efficiency of free chlorine in comparison with chloramines, both as to rapidity of action and as to minimum effective concentration.

The details of laboratory control as practiced in connection with water chlorination will vary to some extent with the manner and objectives of chlorination treatment. The use of chlorination, as a separate and complete method of water treatment, now tends to be limited, with a few exceptions, to the treatment of ground water supplies, as a sanitary safeguard, or to lake or impounded supplies subject to little or no pollution by human wastes. Its most extensive use is in connection with filtration treatment and, in some cases, with coagulation and sedimentation plants having no filters. In general, our experience has indicated that any untreated water containing an average number of coliform bacteria exceeding about 50 per 100 ml. or a water having a high or variable chlorine demand, requires more elaborate treatment than simple chlorination.

The orthotolidin test for residual chlorine is perhaps the most important single control test available to the plant operator. Its details are so familiar that no comment on them seems necessary.

Because of the recent findings concerning the greater bactericidal efficiency of free chlorine, as compared with chloramines, interest in a test which will distinguish both qualitatively and quantitatively between these two forms of chlorine has been increased. Three tests of this kind have been proposed; (1) The orthotolidin "flash" test for free chlorine, which depends on the instantaneous development of a color in the presence of free chlorine; (2) the orthotolidin-arsenate test, which takes advantage of the fact that orthotolidin alone will indicate both free and combined chlorine, whereas orthotolidin with sodium arsenate will react only to chlorine in combined form; and (3) the use of para-aminodimethyl aniline, which does not react with chloramines at ordinary pH values and indicates free chlorine directly.

Where simple, or post filter chlorination, is practiced, the prior addition of ammonia to the untreated water or the presence of any appreciable amount of natural ammonia in the water, leads to the formation of chloramine, though the reaction is somewhat gradual, depending on the temperature and pH of the water. In the initial stage of this reaction, free chlorine may be present for a short time, and can be detected by the tests above mentioned. When the natural ammonia content is low or absent, and no ammonia is added to the water, a large proportion of free chlorine will be present immediately after chlorination, but may become converted to chloramine when brought into contact with ammonia-bearing organic compounds in the distribution pipes and reservoirs. In this case, the most certain method of carrying free chlorine into the distribution system, if it be desirable, is to follow the "break-point" method, which consists in adding amounts of chlorine sufficient to combine with all of the chlorine-demand substances present in the water and leave a stable residual of free chlorine. In piping systems, when break-point chlorination is instituted at the treatment plant, it is necessary to undergo a period of transition during which the unsatisfied chlorine demand in the pipes is being stabilized. In some cases organic growths in the pipes will gradually become loosened and will cause a temporary disturbance in water quality. In time, however, these growths are gradually eliminated from the pipes so that free chlorine can penetrate throughout the distribution system. In such cases, a marked improvement in the freedom of water from chlorinous tastes has been experienced, even with high chlorine residuals.

The control of break-point chlorination usually requires tests, wherein varying amounts of chlorine are added, ranging from 1 to 10 p.p.m., or more, to a series of bottles, and the residuals checked

after a period of time, roughly corresponding to the detention period in the plant basin, or the time of delivery to the nearest water consumer after chlorination. Depending on the ammonia content of the water, a distinct curve of chlorine residuals will be formed with increasing amounts of added chlorine, with a temporary rise followed by a fall, and finally, another rise indicating the presence of free chlorine, which can be checked quantitatively if desired. In practice, this check for free chlorine should be carried out routinely at the plant outlet and at different points in the distribution system. Where ammonia is added to the water to induce a break-point reaction, a check on the total ammonia content should be maintained, in order to allow for the amount of natural ammonia present in gauging the amount of ammonia to be added. This natural ammonia content may vary in some surface waters, notably in flowing streams. In general, chlorine-ammonia ratios of 10:1 or more are necessary in practice in order to provide a residual of free chlorine after the ammonia-chlorine reaction has been completed.

If hypochlorite is used as the disinfectant, the control tests will be similar to those used in the addition of chlorine. In both cases, samples of chlorinated water for bacteriological examination should be collected in sterilized bottles, each containing a crystal of sodium thiosulphate, in order to neutralize the chlorine or chloramine in the sample and thus prevent continued disinfecting action during storage of the sample.

Ground Water Supplies

The laboratory control of ground water supplies is essentially similar to that of surface waters, except for certain special tests which will be noted presently. In general, well waters are clear and low in bacterial content, and seldom contain any considerable numbers of microscopic organisms. Bacteriological plate counts and coliform tests should be made at least once or twice weekly from each source of ground water supply. The coliform determination may be made routinely in five 10 ml. sample portions, or in 100 ml. portions if the test is to be more delicate. Any departure from the normal plate count or coliform number is of course a sign of possible difficulty to be investigated, especially if the source of supply, whether spring or wells, is subject to the possibility of occasional contamination by surface water or sudden rises in the ground water level. As well waters are often hard, a check should be maintained on their total and non-carbonate hardness, and also

their alkalinity and pH value. Nitrites and nitrates should be checked occasionally, particularly if nitrates are high, or if abnormal underground water conditions recur. Departures from the normal balance of organic and inorganic nitrogen in ground waters may be a significant index of change. Where the ground water is chlorinated, a check should be maintained on the ammonia content, for reasons previously noted.

Distribution System Control

The principal objective of distribution system control is to ensure that the sanitary quality of water, as delivered into the system, is maintained at all times and in all parts of the system, or in other words, that no recontamination of the delivered water may occur as the result of any insanitary condition in the distribution system.

In practice, distribution system control usually resolves itself into a preventive task of detection, involving: (1) The collection of samples of water at regular and frequent intervals from various established points in the distribution system; (2) the bacteriological examination of the samples for coliform organisms and, if desirable, for plate-growing organisms; (3) a continuing check on the residual chlorine in the water at the sampling points, with differential tests for free chlorine and chloramine as may be needed; (4) a prompt and careful study of the current laboratory data, in order to detect any lapse in the bacteriological quality, or residual chlorine, at any point in the system; and (5) an immediate and thorough investigation of such lapses whenever they are noted.

There is some evidence that under certain favorable conditions, notably at higher water temperatures, coliform bacteria can multiply in a pipe system. In general, however, any marked increase in the coliform bacteria number in a certain part of the system, as compared with the number observed at the point of discharge into the system, or at other points in the system, should arouse suspicion as to the possibility of local contamination through cross-connections or otherwise. A detailed and accurate record of the location of cross-connections, if any, and of other sanitary hazards in the distribution system, is helpful in interpreting the results of the routine sampling.

In this connection, it is pertinent to note that one of the more important sanitary hazards in water distribution systems, is the existence of certain types of toilet flushing valves and tanks which

may permit back-syphonage if negative pressure is set up in the service pipe or main. Whenever a large main or service pipe is drained for repairs, the possibility of back-syphonage from such toilet fixtures may occur. After repairs have been completed, a bacteriological check on the quality of water in the vicinity of the repair is a good measure of safety. The same principle is also applicable to checking the quality of water in an area of a break in a main, or in an area where a new main or section of main has been installed. In this case, the procedure is similar to that of emergencies, requiring a thorough sterilization of the new or replaced section of pipe with chlorine concentrations of 50 p.p.m. or more. A residual chlorine survey of the area after placing the main into service is a highly desirable sanitary practice, in all cases.

Other problems of distribution systems which need occasional laboratory control measures are concerned with the following types of sanitary hazards:

1. Inadequate protection of distribution reservoirs, stand pipes and elevated pressure tanks.
2. Connections to sprinkling systems using toxic solutions as anti-freeze.
3. Repumping on consumer premises when pressure is low (causing negative pressure).
4. Connection to sewers and sewer-flushing chambers, and improperly located blow-offs in the distribution system.
5. Lack of check valves to prevent back-flow on consumer premises from ammonia systems at ice plants or from hot water systems.
6. Presence of secondary water systems on premises served by the public system.
7. Existence of tile or other leaky pipes in the distribution system.
8. Improper location of water pipes in relation to sewers and storm water drains.

General Trends in Laboratory Control Methods

A marked tendency in recent laboratory control practice has been the development and adaptation of new physical and electrometric devices for facilitating more precise measurements and minimizing the possibilities for errors due to the personal equation. In a recent article[3] Graham has described some of these newer devices. In this article he notes among the general physical devices the following:

1. pH meter and electrometric titration equipment.
2. Conductivity equipment.
   a. Microphone hummer and telephone receiver.
   b. Alternating current galvanometer.
   c. Electronic bridge-balance indicator.

[3] Graham, Jour. Am. Water Works Association, October, 1945, p. 983.

3. Colorimetric equipment.
   a. Colorimeter.
   b. Photo-electric photometer.
   c. Spectrophotometer.
4. Turbidimeter.
   a. Hellige (Tyndall ray principle).
   b. Baylis.
   c. Photo-electric.
5. Microscope.
   a. Stereoscopic low power.
   b. Photomicrographic equipment.
6. Spectrograph.
7. Water de-Mineralizer (as a substitute for distillation).
8. Vacuum oven.

In the field of chemical water analysis, the following developments have been noteworthy:

1. The estimation of dissolved solids in water by means of the conductivity test.
2. Refinements in the soap test for hardness.
3. New methods of determining carbonate equilibria—calculation of CO_2, normal CO_3, and OH from pH and alkalinity, using the DeMartini equations.
4. Changes in the limiting requirements for chemical substances present in drinking water supplies have been provided in the revised standards of the United States Public Health Service. These changes have included: (a) An increase in the allowable copper content to 3. p.p.m.; (b) fixing a limit for fluoride at 1.0 p.p.m., and of selenium at 0.05 p.p.m.; and (c) excluding wholly salts of barium, hexavalent chromium, and heavy metal glucosides, as being physiologically deleterious for human consumption.

In the field of water bacteriology, the following trends have been noteworthy:

1. Simplification of the confirmed fermentation test for coliform bacteria, and renewed efforts to develop direct plating methods for enumerating organisms of this group.
2. Limitation of the standard agar or gelatin plate count to the measurement of water purification efficiencies, and the determination of bacteria of non-sanitary significance in water supplies.
3. Studies of possible index organisms in water supplies other than coliform bacteria, such as the salmonella, pseudomonas, and streptococcus groups.

In summing up this subject, it may be noted that technical progress in the laboratory control of water supplies have been well marked during the past few years and probably will receive a fresh impetus as the newer physical devices and improvements in laboratory methods based on these devices come into wider use. The increasing responsibility of the laboratory man for the proper sanitation of water distribution, together with his more active concern in the conditioning of water for industrial purposes, and in making water supplies softer and more palatable for domestic uses, has opened new fields of advance in water technology.

The sanitary engineer may profit from these advances, by seeking to gain a thorough knowledge of their underlying principles, and by adapting them to the solution of his own problems in the engineering phases of water sanitation. It is largely through a concerted attack on these problems by the engineer, chemist, bacteriologist, and biologist, working as a closely cooperative group, that the greatest progress can be made in the struggle of our urban populations to control the safety and palatability of that most vital element of their continued prosperity and, indeed, of their survival as organized communities, the public water supply.

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